

# Predictions of a Natural SUSY Dark Matter Model for Direct and Indirect Detection Experiments

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## Abstract

The most natural region of cosmologically compatible dark matter relic density in terms of low fine-tuning in a minimal supersymmetric standard model with nonuniversal gaugino masses is the so called bulk annihilation region. We study this region in a simple and predictive SUSY-GUT model of nonuniversal gaugino masses, where the latter transform as a combination of singlet plus a nonsinglet representation of the GUT group SU(5). The model prediction for the direct dark matter detection rates is well below the present CDMS and XENON100 limits, but within the reach of a future 1Ton XENON experiment. The most interesting and robust model prediction is an indirect detection signal of hard positron events, which resembles closely the shape of the observed positron spectrum from the PAMELA experiment.

# 1 Introduction

The most phenomenologically attractive feature of supersymmetry and in particular the minimal supersymmetric standard model (MSSM) is that it offers a natural candidate for dark matter in terms of the lightest superparticle (LSP) [1]. Astrophysical constraints on dark matter requires it to be a neutral and colourless particle, while direct detection experiments strongly disfavour a sneutrino LSP. That makes the lightest neutralino state  $\tilde{\chi}_1^0$  (abbreviated as  $\chi$ ) the favoured candidate for dark matter in the MSSM. In the constrained version of the model (CMSSM), corresponding to universal gaugino and scalar masses at the GUT scale, the lightest neutralino state is dominantly a bino over most of the parameter space. Since the bino carries no gauge charge, its main annihilation mechanism is via sfermion exchange in the t-channel. This is usually called the bulk annihilation process; and the region of parameter space giving cosmologically compatible dark matter relic density via this mechanism is called the bulk region. It provides the most natural solution to the dark matter problem, in the sense that the desired dark matter relic density can be obtained in this region with practically no fine-tuning. However, LEP sets rather stringent lower limits on the bino LSP as well as the sfermion masses in the CMSSM, which rules out the parameter space of the bulk annihilation region [2].

The reason for the large bino and sfermion mass limits mentioned above is that the LEP lower limit on the neutral Higgs boson mass of the MSSM requires a large radiative correction from top Yukawa coupling, which in turn requires a large stop mass in order to suppress the canceling contribution from stop exchange. This in turn requires a large gluino mass contribution to the RGE of stop mass. Since the GUT scale gluino and bino masses are equal in the CMSSM, this constraint also implies large bino and sfermion masses at the weak scale via their RGE. Evidently a simple way to make the bulk annihilation region of the MSSM dark matter compatible with the Higgs mass limit from LEP is to give up the universality of gaugino masses at the GUT scale; and in particular to assume that the GUT scale bino mass is significantly smaller than that of gluino. Then the latter can ensure the Higgs mass limit from LEP, while the former ensures relatively small bino and right-handed slepton masses at the weak scale via their RGE, as required for the bulk annihilation region. Moreover there are simple and well motivated models for nonuniversal gaugino masses at the GUT scale, where one assumes that the latter get contributions from SUSY breaking superfields belonging to the nonsinglet representations of the GUT group [3]. One can combine these two observations to construct simple and predictive nonuniversal gaugino mass models, which provide a natural solution to the

dark matter relic density while satisfying all the LEP constraints.

The issue of naturalness and fine-tuning involved in achieving the right dark matter relic density [4] was investigated in [5] for a generic MSSM with nonuniversal gaugino masses. Assuming the usual measure of fine-tuning,

$$\Delta_a^\Omega = \frac{\partial \ln(\Omega_{CDM} h^2)}{\partial \ln(a)} \quad \& \quad \Delta^\Omega = \max(\Delta_a^\Omega), \quad (1)$$

where  $a$  refers to the input parameters of the model [6], it was found that  $\Delta^\Omega \sim 1$  over the bulk region. This means there is practically no fine-tuning involved in achieving the desired dark matter relic density over the bulk region. In fact over most of this region  $\Delta^\Omega$  was found to be slightly less than 1, for which the authors called the bulk region 'supernatural' for achieving the desired dark matter relic density. In contrast all the other regions of right dark matter relic density like the stau-coannihilation, the resonant-annihilation and the focus-point regions had 1-2 orders of magnitude higher values of this fine-tuning measure.

Subsequently this issue was investigated in a set of simple and predictive nonuniversal gaugino mass models, where the GUT scale gaugino masses are assumed to get contributions from a combination of two SUSY breaking superfields belonging to singlet and nonsinglet representations of the GUT group SU(5) [7] - i.e. the combinations 1+24, 1+75 and 1+200. In each case one could access the bulk region with  $\Delta^\Omega \sim 1$ , implying practically no fine-tuning required to achieve the right dark matter relic density. In the present work we have investigated the signatures of this set of natural SUSY dark matter models for direct and indirect detection experiments. In section 2, we summarize the essential ingredients of the model. In section 3, we present some representative SUSY mass spectra of this model and briefly comment on their implications for the signatures of the model at LHC. Then we present the model predictions for direct and indirect dark matter detection experiments in sections 4 and 5 respectively. In particular we shall see in section 5 that the model predicts a hard positron spectrum like that reported by the PAMELA experiment [8], though it cannot account for the required boost factor in the rate. We conclude with a brief summary of our results in section 6.

## 2 Nonuniversality of Gaugino Masses in SU(5) GUT

The above set of models is based on the assumption that SUSY is broken by a combination of two superfields belonging to singlet and a nonsinglet representation of the simplest GUT group SU(5) [3]. The gauge kinetic function responsible for the GUT scale gaugino masses originates from the vacuum expectation value of the F term of a chiral superfield  $\Omega$  responsible for SUSY breaking,

$$\frac{\langle F_\Omega \rangle_{ij}}{M_{Planck}} \lambda_i \lambda_j, \quad (2)$$

where  $\lambda_{1,2,3}$  are the U(1), SU(2), SU(3) gaugino fields - bino, wino and gluino. Since the gauginos belong to the adjoint representation of the GUT group SU(5),  $\Omega$  and  $F_\Omega$  can belong to any of the irreducible representations appearing in their symmetric product,

$$(24 \times 24)_{sym} = 1 + 24 + 75 + 200. \quad (3)$$

Thus, the GUT scale gaugino masses for a given representation of the SUSY breaking superfield are determined in terms of one mass parameter by

$$M_{1,2,3}^G = C_{1,2,3}^n m_{1/2}^n \quad (4)$$

where

$$C_{1,2,3}^1 = (1, 1, 1), \quad C_{1,2,3}^{24} = (-1, -3, 2), \quad C_{1,2,3}^{75} = (-5, 3, 1), \quad C_{1,2,3}^{200} = (10, 2, 1). \quad (5)$$

The CMSSM assumes  $\Omega$  to be a singlet, leading to universal gaugino masses at the GUT scale. On the other hand, any of the nonsinglet representations for  $\Omega$  would imply nonuniversal gaugino masses via eqs (4) and (5). These nonuniversal gaugino mass models are known to be consistent with the observed universality of gauge couplings at the GUT scale [3, 9], with  $\alpha^G \simeq 1/25$ . The phenomenology of these models have been widely studied [10]. Note that each of these nonuniversal gaugino mass models is as predictive as the CMSSM. However, none of them can evade the above mentioned LEP constraint to access the bulk region. This can be achieved by assuming SUSY breaking via a combination of a singlet and a nonsinglet superfields [7], where the GUT scale gaugino masses are given in terms of two mass parameters,

$$M_{1,2,3}^G = C_{1,2,3}^1 m_{1/2}^1 + C_{1,2,3}^l m_{1/2}^l \quad \& \quad l = 24, 75 \text{ or } 200. \quad (6)$$

Then the weak scale superparticle masses are given in terms of these gaugino masses and the universal scalar mass parameter  $m_0$  via the RGE. In particular the gaugino masses evolve like the corresponding gauge couplings at the one-loop level of the RGE, i.e.

$$\begin{aligned} M_1 &= \left( \frac{\alpha_1}{\alpha_G} \right) M_1^G \simeq \left( \frac{25}{60} \right) C_1^m m_{1/2}^n \\ M_2 &= \left( \frac{\alpha_2}{\alpha_G} \right) M_2^G \simeq \left( \frac{25}{30} \right) C_2^m m_{1/2}^n \\ M_3 &= \left( \frac{\alpha_3}{\alpha_G} \right) M_3^G \simeq \left( \frac{25}{9} \right) C_3^m m_{1/2}^n \end{aligned} \quad (7)$$

The Higgsino mass parameter  $\mu$  is obtained from the electroweak symmetry breaking condition along with the one-loop RGE for the Higgs scalar mass, i.e.

$$\mu^2 + \frac{M_Z^2}{2} \simeq -m_{H_u}^2 \simeq -0.1m_0^2 + 2.1(M_3^G)^2 - 0.22(M_2^G)^2 + 0.19M_2^G M_3^G \quad (8)$$

neglecting the contribution from the GUT scale trilinear coupling term  $A_0$  [11]. The numerical coefficients on the right correspond to a representative value of  $\tan \beta = 10$ ; but they show only mild variations over the moderate  $\tan \beta$  region. Although we shall be evaluating the weak scale superparticle masses using the two-loop RGE code `SuSpect`[12], the approximate formulae (7) and (8) will be useful in understanding some essential features of the results.

### 3 The SUSY Spectra at the Weak Scale

It was shown in the Fig 4 of ref [5] that the bulk region extends over the parameter range

$$M_1^G = 150 - 250 \text{ GeV} ; \quad m_0 = 50 - 80 \text{ GeV} \quad (9)$$

with a mild anti-correlation between the two parameters. This is because the main annihilation process for the bino LSP pair is via right-handed slepton exchange

$$\chi\chi \xrightarrow{\tilde{l}_R} \bar{l}l \quad (10)$$

and the bino mass is determined by  $M_1^G$  via the RGE (7), while the right-handed slepton mass is determined via its RGE by  $M_1^G$  and  $m_0$  with a mild anti-correlation between the two parameters. Therefore we have chosen to use two set of input parameters

$$M_1^G = 200 \text{ GeV}, m_0 = 70 \text{ GeV} \quad \& \quad M_1^G = 250 \text{ GeV}, m_0 = 67 \text{ GeV} \quad (11)$$

to represent the centre and the upper edge of the bulk region. The latter set predicts a relatively hard positron spectrum for the indirect detection signal similar to that of the PAMELA experiment as we shall see in section 5. For the second gaugino mass parameter we have chosen to use  $M_3^G$  as input, since it makes the dominant contribution to the weak scale gluino and squark masses as well as the corresponding Higgsino mass of eq (8). The remaining gaugino mass  $M_2^G$  is then determined in terms of these  $M_1^G$  and  $M_3^G$  using eqs (4-6). Using these GUT scale gaugino masses along with the scalar mass  $m_0$  as inputs to the RGE code **SuSpect** [12], we have evaluated the weak scale SUSY spectra for a representative value of  $\tan \beta = 10$ , where we have neglected the contribution from the GUT scale trilinear coupling term  $A_0$ .

We shall concentrate on the 1+75 and 1+200 models, for which the dominant contributions to the gaugino masses satisfying the bulk region come from the singlet superfields [7]. Tables 1 and 2 show the weak scale SUSY spectra in the 1+75 and 1+200 models for the two representative points of the bulk region (eq.11) and  $M_3^G = 800 \text{ GeV}$ . As expected the squark and gluino masses are primarily determined by  $M_3^G$  irrespective of the choice of the nonsinglet representation or the values of  $M_1^G$  and  $m_0$ . The mass range of 1500-1700 GeV for the squark and gluinos lie outside the discovery limit of 7-8 TeV LHC but well within that of the 14 TeV run. While the masses of the wino and the left-handed sleptons depend on the choices of the nonsinglet representation and the input mass parameters, the small  $m_0$  values ensure that the latter is always lighter. Thus the SUSY cascade decay at LHC is expected to proceed via the left-handed selectron/smuon or one of the two stau states, leading to a distinctive SUSY signal containing a hard  $e/\mu$  or  $\tau$ -jet along with the missing- $E_T$ . However, a quantitative analysis of these LHC signatures is beyond the scope of the present work.

The predicted value of the light Higgs boson mass for the SUSY spectra of Tables 1 and 2 is 119 GeV. It can be increased by a few GeV via stop mixing by using a moderately large and negative  $A_0$  for the squark sector [13, 14]

$$M_1^G = 200 \text{ GeV}, M_3^G = 800 \text{ GeV}, m_0 = 70 \text{ GeV}$$

Particle	Mass (GeV)	
	(1+75) model	(1+200) model
$\tilde{\chi}_1^0$ (bino)	78.4	78.0
$\tilde{\chi}_2^0$ (wino)	783	582
$\tilde{\chi}_3^0$ (higgsino)	929	970
$\tilde{\chi}_4^0$ (higgsino)	954	979
$\tilde{\chi}_1^+$ (wino)	783	582
$\tilde{\chi}_2^+$ (higgsino)	954	979
$M_1$	79.9	79.7
$M_2$	791	574
$M_3$	1718	1723
$\mu$	925	965
$\tilde{g}$	1766	1766
$\tilde{\tau}_1$	86.3	90.8
$\tilde{\tau}_2$	637	470
$\tilde{e}_R, \tilde{\mu}_R$	108	107
$\tilde{e}_L, \tilde{\mu}_L$	638	470
$\tilde{t}_1$	1219	1251
$\tilde{t}_2$	1544	1506
$\tilde{b}_1$	1513	1479
$\tilde{b}_2$	1531	1528
$\tilde{q}_{1,2,R}$	$\sim 1527$	$\sim 1533$
$\tilde{q}_{1,2,L}$	$\sim 1643$	$\sim 1592$

**Table 1:** The SuSy mass spectrum for the (1+75) and (1+200) models for a  $\sim 80$  GeV LSP. We display the hierarchy and flavour of the neutralino and chargino sectors. We also display the values of the neutralino mass parameters for completeness. For the squarks we take a typical squark mass rather than list the full squark spectrum. The exceptions are the 3rd family squarks that we list separately. Finally, the sneutrinos are degenerate with  $\tilde{e}, \tilde{\mu}_L$ . The lightest higgs mass in this case is 119 GeV for both models.

$$M_1^G = 250 \text{ GeV}, M_3^G = 800 \text{ GeV}, m_0 = 67 \text{ GeV}$$

Particle	Mass (GeV)	
	(1+75) model	(1+200) model
$\tilde{\chi}_1^0$ (bino)	100	99.6
$\tilde{\chi}_2^0$ (wino)	772	586
$\tilde{\chi}_3^0$ (higgsino)	933	970
$\tilde{\chi}_4^0$ (higgsino)	955	979
$\tilde{\chi}_1^+$ (wino)	772	586
$\tilde{\chi}_2^+$ (higgsino)	955	979
$M_1$	102	102
$M_2$	778	579
$M_3$	1718	1723
$\mu$	928	965
$\tilde{g}$	1766	1766
$\tilde{\tau}_1$	100	104
$\tilde{\tau}_2$	627	474
$\tilde{e}_R, \tilde{\mu}_R$	119	119
$\tilde{e}_L, \tilde{\mu}_L$	628	474
$\tilde{t}_1$	1221	1251
$\tilde{t}_2$	1541	1507
$\tilde{b}_1$	1512	1480
$\tilde{b}_2$	1529	1528
$\tilde{q}_{1,2,R}$	$\sim 1528$	$\sim 1533$
$\tilde{q}_{1,2,L}$	$\sim 1640$	$\sim 1593$

**Table 2:** The SUSY mass spectrum for the (1+75) and (1+200) models for a 100 GeV LSP. Once again the lightest higgs mass is 119 GeV.



$$M_1^G = 250 \text{ GeV}, M_3^G = 800 \text{ GeV}, m_0 = 80 \text{ GeV}$$

Particle	Mass (GeV)	
	(1+75) model	(1+200) model
$\tilde{\chi}_1^0$ (bino)	101	101
$\tilde{\chi}_2^0$ (wino)	789	593
$\tilde{\chi}_3^0$ (higgsino)	1197	1218
$\tilde{\chi}_4^0$ (higgsino)	1206	1223
$\tilde{\chi}_1^+$ (wino)	789	592
$\tilde{\chi}_2^+$ (higgsino)	1206	1223
$M_1$	103	103
$M_2$	780	581
$M_3$	1728	1732
$\mu$	1197	1217
$\tilde{g}$	1766	1767
$\tilde{\tau}_1$	109	111
$\tilde{\tau}_2$	649	478
$\tilde{e}_R, \tilde{\mu}_R$	128	128
$\tilde{e}_L, \tilde{\mu}_L$	631	477
$\tilde{t}_1$	1056	1096
$\tilde{t}_2$	1488	1455
$\tilde{b}_1$	1459	1421
$\tilde{b}_2$	1519	1524
$\tilde{q}_{1,2,R}$	$\sim 1531$	$\sim 1536$
$\tilde{q}_{1,2,L}$	$\sim 1643$	$\sim 1597$

**Table 3:** The SUSY mass spectrum for the 1+75 and 1+200 models for a LSP mass of 100 GeV obtained with  $A_t = A_b = -1.3$  TeV and  $A_\tau = 0$  TeV. It predicts a light Higgs mass of 122 GeV, which agrees with the reported value of 125 GeV within the model uncertainty of  $\sim 3$  GeV.

to bring it closer to the reported value of about 125 GeV [15, 16]. It may be noted here that there is an uncertainty of  $\sim 3$  GeV in the SUSY model prediction of the light Higgs boson mass arising mainly from the renormalisation scheme dependence along with the experimental uncertainty in top quark mass [17, 18, 19, 20, 21, 22]. In particular the on-shell renormalisation scheme prediction is higher by 2-3 GeV relative to that of the MS-bar scheme used in **SuSpect**. Therefore we have computed the SUSY spectrum analogous to Table 2, but with  $A_0=-1.3$  TeV for the squark sector, which raises the Higgs mass to the acceptable range of 122 GeV, as shown in Table 3. We see by comparing this with Table 2 that there is very little difference between the respective SUSY mass spectra except for a modest increase of the  $\mu$  parameter and the resulting higgsino masses.

## 4 Prediction for Direct Dark Matter Detection Experiments

The direct dark matter detection experiments are mainly based on its elastic scattering on a heavy nucleus like Germanium or Xenon, which is dominated by the spin-independent  $\chi p$  scattering contribution mediated by the Higgs boson exchange. Since the Higgs coupling to the lightest neutralino  $\chi$  is proportional to the product of its gaugino and higgsino components, the direct detection cross-section is predicted to be small for a bino dominated

$M_1^G$	$M_3^G$	$m_0$	
		1 + 75	1 + 200
150	600	80	80
	800	80	80
	1000	89	80
200	600	70	70
	800	70	70
	1000	77	70
250	600	60	60
	800	70	66
	1000	83	76

**Table 4:** The values of  $m_0$ ,  $M_1^G$  and  $M_3^G$  used for the benchmark points shown in Fig. 1.

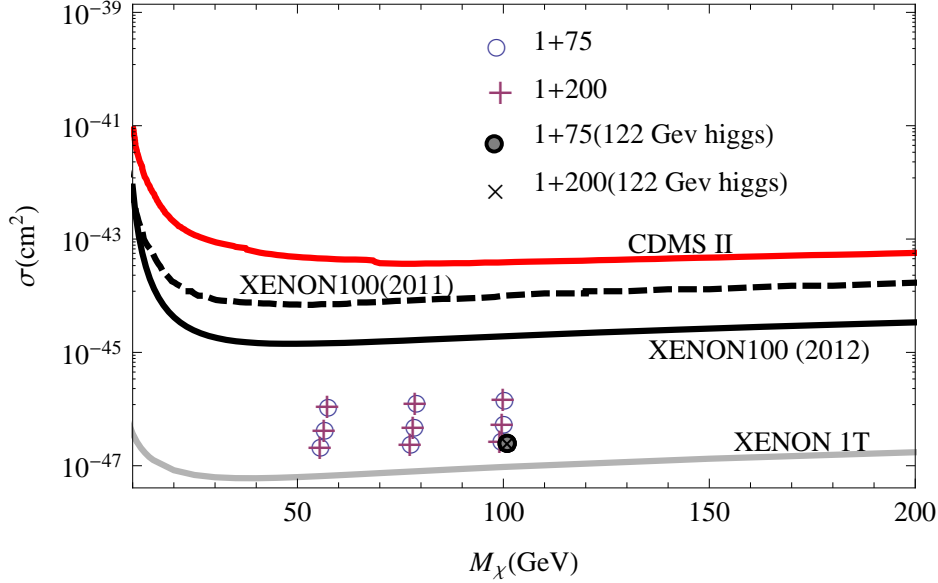
$\chi$  state. Fig 1 shows the predicted spin-independent  $\chi p$  cross-section for the 1+75 and 1+200 models for 3 representative points in the bulk region listed in Table 4 with  $M_3^G = 600, 800$  and  $1000$  GeV. We do not show the prediction for lower values of this parameter since  $M_3^G = 500$  GeV corresponds to both squark and gluino masses in the range of 1000 to 1200 GeV, which may have been already ruled out by the 7 TeV LHC data [23]. Note that the size of the higgsino component of  $\chi$  goes down with increasing higgsino mass  $\mu$ , which is primarily determined by  $M_3^G$  via eq (8). Therefore the direct detection cross-section goes down steadily with increasing  $M_3^G$  with very little dependence on the choice of the nonsinglet representation or the other input parameters. We show in this figure the current upper limits on this cross-section from the CDMS [24] and XENON100 [25] experiments along with the projected limit from a future 1 Ton XENON experiment [26]. The predicted rates are seen to be well below the current experimental limits. However, they are within the reach of 1 Ton XENON experiment.

## 5 Predictions for Indirect Dark Matter Detection Experiments

The indirect dark matter detection experiments are based on detecting the products of dark matter pair-annihilation at the present time. Since the dark matter particles are highly non-relativistic ( $v \sim 10^{-3}$ ), only the s-wave annihilation cross-section is of any significance at the present time. One can then show from symmetry considerations that for Majorana particles like the neutralino  $\chi$  the cross-section for the annihilation process (10) is helicity suppressed by a factor of  $(m_l/M_W)^2$ . In contrast cross-section for the radiative annihilation process

$$\chi\chi \xrightarrow{\tilde{l}_R} \bar{l}l\gamma \quad (12)$$

is only suppressed by a factor of  $\alpha$  [27]. Therefore it provides the dominant annihilation mechanism at the present time. It can be observed by detecting the electron/positron, photon or neutrino (coming from decay of  $\mu$  and  $\tau$  leptons). A popular indirect detection experiment is IceCube [28], looking for high energy neutrinos coming from the dark matter pair-annihilation inside the sun. In this case the signal size is determined by the dark matter capture cross-section by the solar matter, which is mainly proton; and the main contribution comes from the spin dependent scattering via  $Z$  boson exchange. Unfortunately, the  $Z$  boson coupling to  $\chi$  is proportional to the square of its higgsino component, which is very highly suppressed for the



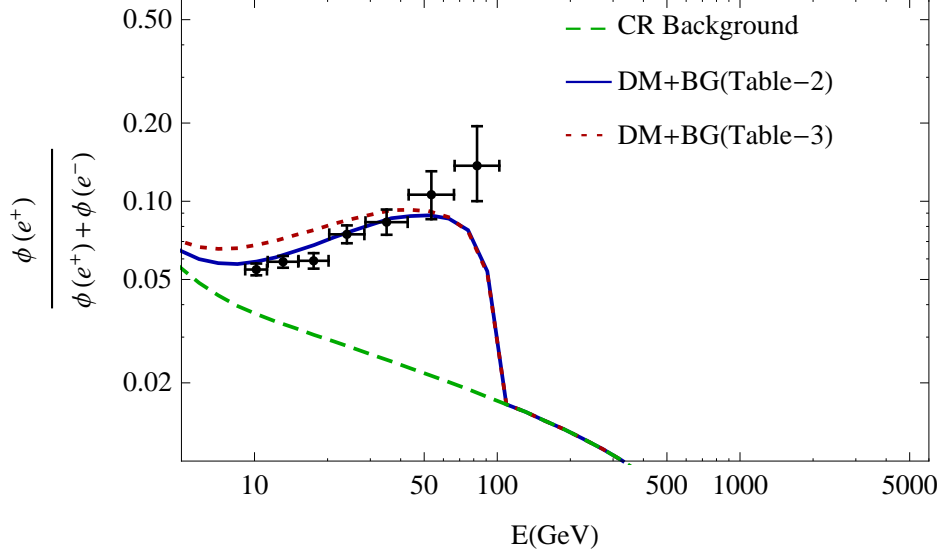
**Figure 1:** Plot shows the spin independent (SI) neutralino-proton cross section as a function of LSP mass for the 1+75 and 1+200 models. The value of  $m_0$ ,  $M_1^G$  and  $M_3^G$  used for each point shown in the figure are as per Table 4. With increasing value of  $M_3^G$  the cross section goes down while  $M_1^G$  fixes the LSP mass. Limits from CDMSII[24] (in red), XENON100[25] (in black) and the possible exclusion limits from the future XENON1T[26] (in grey) are also shown. The present exclusion limit from XENON100 [25] is down to  $2 \times 10^{-45} \text{cm}^2$  ( for DM mass  $\sim 55$  GeV) at 90 % C.L. We also show the direct detection result for the spectrum in Table 3 ( filled circle and cross). This spectrum shows an increase in the  $\mu$  parameter and higgsino masses compared to the spectrum in Table 2, resulting in a smaller higgsino component in the predominantly bino LSP which leads to a slight decrease in the direct detection rate.

bino dominated dark matter of our interest. Therefore it offers no viable signal for such experiments.

The most promising signal in this case is provided by the hard positron spectrum coming from the annihilation process (12). We have evaluated this positron spectrum by computing the annihilation cross-section for (12) using DarkSUSY [29], followed by the propagation of positron using Galprop [30]. We have used the isothermal dark matter density profile[31] in our computation. Fig 2 shows the shape of the predicted positron spectrum relative to electron for a 100 GeV bino dark matter, corresponding to the SUSY mass spectrum of Table 2. The shape of the observed positron spectrum from the PAMELA experiment [8] is also shown for comparison. The shape of

the predicted positron spectrum agrees well with the PAMELA data, with only the prediction undershooting the last data point by two standard deviations. One may be tempted to fit the last data point by increasing the bino dark matter mass to 120-130 GeV. However, this will take us into the stau co-annihilation region, which requires significantly higher fine-tuning than the bulk region. Moreover, the shape of the signal gets flatter with the increasing DM mass, which increases the overall discrepancy between the predicted spectrum and the data. Indeed the positron signal from (12) was already studied in the stau co-annihilation region in ref [27], which compared the PAMELA spectrum with the model predictions for DM masses of 132 and 233 GeV in its Fig 3. A comparison of that figure with our present Fig 2 shows an evident deterioration of the overall fit with the PAMELA spectrum by increasing the dark matter mass from 100 to 132 GeV, which is further aggravated by increasing the mass further to 233 GeV. The rise of the PAMELA spectrum has a low threshold of  $\sim 20$  GeV, which makes it hard to fit with a dark matter mass larger than 100 GeV via the annihilation process (12). Therefore an extension of the positron spectrum beyond 100 GeV from PAMELA or the forthcoming AMS2 [32] data will provide a decisive test for this annihilation process.

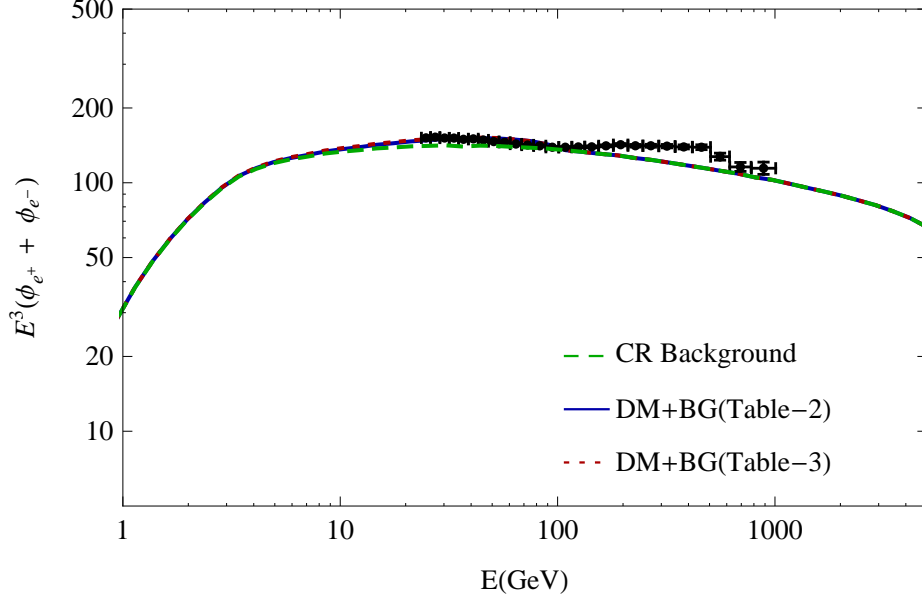
Note that the annihilation process (12) does not produce any anti-proton; and hence predicts no anti-proton excess over the cosmic ray background in agreement with the PAMELA data. The main problem in comparing the model prediction with the PAMELA data is that it requires a large boost factor of  $\sim 7000$  for explaining the size of the observed positron signal. One can understand this factor as follows. In the most favorable scenario, where the dark matter is a Dirac particle so that there is no helicity suppression, the same annihilation process (10) determines the relic density as well as the size of the PAMELA positron signal [33]. In this scenario one needs the most modest boost factor of  $\sim 30$ . In the present model with Majorana dark matter the annihilation process (12) responsible for the positron signal is suppressed by a factor of  $\alpha$  relative to process (10) at the freeze-out point, which determines the relic density. Therefore for the same relic density the required boost factor for the positron signal needs to be higher by a factor of  $1/\alpha$ , which takes it up to  $\sim 7000$ . It should be added here that the stau-coannihilation region studied in [27], requires an even larger boost factor of  $\sim 30,000$ . This is because in that case the pair annihilation process (10) makes a small contribution relative to stau-coannihilation to the total annihilation cross-section at freeze-out and the resulting relic density. Therefore one requires almost an order of magnitude larger boost factor for the stau-coannihilation region compared to the bulk region. Admittedly, in neither case one has any explanation for such large boost factors in the SUSY model.



**Figure 2:** Ratio of the positron flux to the total ( $e^- + e^+$ ) flux vs energy for a 100 GeV DM in the 1+75 model, with PAMELA data shown for comparison. The solid line denotes the result for the spectrum in Table 2 and the dotted line for Table 3. The boost in the annihilation cross section is taken to be 7000 and 10000 respectively.

Therefore, one needs to attribute this factor to astrophysical sources like a local population of intermediate mass black holes leading to spikes in the dark matter density distribution [34], or a nearby dark matter clump [35].

For the reason mentioned earlier, the annihilation process (12) cannot simultaneously account for the steep rise in the PAMELA positron spectrum as well as the sustained hardness of the ( $e^- + e^+$ ) spectrum from the FERMI-LAT data [36], spanning over several hundreds of GeV. Therefore, we assume following [37], that the latter can be accounted for by modifying the cosmic ray propagation parameters within their experimental uncertainty. Fig 3 shows the predicted ( $e^- + e^+$ ) spectrum with modified cosmic ray propagation parameters together with the FERMI-LAT data. However, we have not tried to make a detailed fit with the latter by using a larger number of propagation parameters, as this exercise is not central to the main issue of our paper. Finally, Fig 4 compares the predicted  $\gamma$  ray spectrum from the annihilation process (12) along with the cosmic ray background with the FERMI-LAT data [38]. In this case the signal peak seems too small to extract from the cosmic ray background contribution to this data.



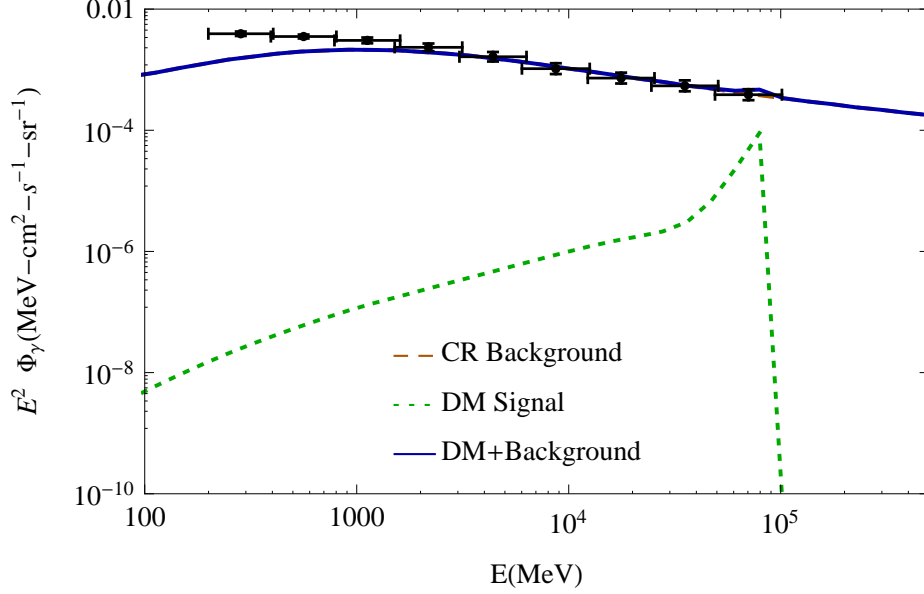
**Figure 3:** The total  $(e^+ + e^-)$  flux vs energy for a 100 GeV DM with the corresponding data from FERMI shown for comparison. The solid line denotes the result for the spectrum in Table 2 and the dotted line for Table 3. The boost in the annihilation cross section is taken to be 7000 and 10000 respectively.

## 6 Conclusions

Motivated by the observation that the bulk region of dark matter relic density can be achieved without fine tuning in models with non-universal gaugino masses at the GUT scale, specifically those arising from a combination of two SUSY breaking superfields belonging to singlet and non-singlet representations of SU(5) [7], we investigate the dark matter phenomenology of these models.

We study the signals of the 1+75 and 1+200 models of [7] in direct and indirect detection experiments. We scan the parameter space  $M_1^G=150-250$  GeV and  $m_0=80-50$  GeV which corresponds to the bulk region and where the bino LSP mass has mass in the range 60-100 GeV. The gluino mass is taken in the range  $M_3^G=600-1000$  GeV to evade the bounds on squark and gluino masses from the 7 TeV LHC data [23].

The direct detection cross section for the  $\chi p$  scattering is small for a primarily bino LSP because it is mediated by the higgs which couples to the gaugino and Higgsino components of  $\chi$ . The recent Xenon100 result with 225 day exposure rules out DM-proton SI-cross section of up to  $2 \times 10^{-45} \text{cm}^2$



**Figure 4:** Diffuse gamma ray flux from 100 GeV DM with data from the FERMI-LAT shown for comparison. The boost in the annihilation cross section is taken to be 7000.

[25]. The 1+75 and 1+200 models studied have a lower  $\chi p$  cross section (Fig 1) and these models are consistent with direct detection experiments so far. A future Xenon 1T experiment which can probe  $\chi p$  cross sections as low as  $10^{-47} \text{ cm}^2$  will provide a stringent test of these models.

The dominant process for indirect detection signal of dark matter is via the s-wave radiative annihilation,  $\chi\chi \xrightarrow{\tilde{l}_R} \bar{l}l\gamma$  [27]. This will contribute to the flux of electron/positrons, photons and neutrinos from  $\mu$  and  $\tau$  decays. We find that the 100 GeV bino DM can make a significant contribution to the positron excess observed by PAMELA [8]. We see from Fig 2 that the DM annihilation can explain the positron excess (barring the last data point where the signal is lower than the data within 2-sigma) with a boost factor of  $\sim 7000$ . Such a boost factor may be attributed to astrophysical sources[34, 35] We do not consider a higher DM mass as that would require obtaining the required relic density by stau-coannihilation which would involve a large fine tuning of the parameters at the GUT scale. Moreover the pair annihilation cross section in the stau-coannihilation regime is smaller so a much larger boost factor  $\sim 30,000$  is required [27] in order to explain the PAMELA positron signal. The measurement of positron flux beyond 100 GeV by AMS2 [32]



will provide a stringent test of the natural dark matter models [7].

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